

The University of Chicago

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SLEEP. CHANGES IN IRRITABILITY
TO AUDITORY STIMULI DURING
SLEEP

A DISSERTATION SUBMITTED TO THE
FACULTY OF THE DIVISION OF THE
BIOLOGICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSIOLOGY

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Reprinted from
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STUDIES ON THE PHYSIOLOGY OF SLEEP CHANGES IN IRRITABILITY TO AUDITORY STIMULI DURING SLEEP *

BY F. J. MULLIN

From the Department of Physiology of the University of Chicago

The basis for the construction of the classical curves of the 'depth of sleep' as found in the literature and textbooks of psychology and physiology is the work on the intensity of stimulus necessary to awaken a sleeping subject at various times during the night. Such studies were made by Kohlschutter (5), 1862, using the sound produced by a pendulum falling from a height onto a slate plate; by Monninghof and Piesbergen (8), 1883, who employed a lead ball falling on an iron plate; by Michelson (7), 1891, with the use of various brass balls falling from a given height to a table; and by Czerny (1), 1891, using induction shocks. These so-called curves of the intensity of sleep all show a peak during the first or second hour of sleep followed by a drop to a low level. In some of these and also in other early curves obtained by similar methods, particularly that of Lambranzi (6), 1900, there occurs a later peak of about half the height of the first, coming near the end of the sleep period. In 1923 Hass (2), stimulating with a sound, found that the intensity necessary to awaken was very great thirty minutes after the onset of sleep and was considerably less during the remainder of the night.

In 1933 Kleitman, Cooperman and Mullin (4) reported motility changes during sleep which, when plotted on an hourly basis, gave a curve roughly inverse to those of the depth of sleep. On the other hand, the curve of the distribution of periods of immobility of half an hour or longer in

* This work was aided by a grant from the Rockefeller Foundation. Thanks are due to Messrs. N. Brewer, A. T. Doktorsky, M. Hanley, N. Morris, Y. T. Oester, L. Palitz, I. Rossman and S. Titelbaum for their valuable assistance in obtaining the data reported, and especially to Drs. N. Kleitman and N. R. Cooperman.

duration during the night bears a close resemblance to these classical curves of the depth of sleep. The similarity of these two types of curves led to the development of a working hypothesis that the apparent depth of sleep as determined by the intensity of the stimulus necessary to awaken the sleeper might be a function of the length of time that elapsed after he had changed his position.

METHODS

This study consists of two parts: the determination of the changes in irritability to auditory stimuli which occur in a dog when it goes to sleep, and the determination of the intensity of auditory stimuli necessary to awaken a human sleeper at various times during the night in relationship to his motility. In both cases the auditory stimulus was delivered by a magnetic loudspeaker connected to a 110-volt A.C. outlet through a rheostat. The rheostat dial was graduated from 0 to 100, and the voltage represented by the figures on the dial was calibrated by means of a voltmeter. It was thus possible to grade the intensity of current flowing to the loud-speaker, and to use this as a measure of the loudness of the sound emitted by the latter.

In the dog experiments the animal was placed in a stand which held its head in place and which could easily be adjusted to the height of the dog. A wide band of ticking was passed underneath the dog's body as a sort of sling, which was loose enough so that if the dog stood on its own feet the sling would pass freely under its belly, but the dog had only to relax a bit and the sling would then support it. The legs of the dog were entirely free. The dogs had been taught to remain in the stand quietly. The operator would stay in an adjoining room and observe the animal continuously through a peep-hole in a covered glass window so arranged that the dog could not see the observer. The main criterion as to whether the dog was asleep or not was the observation of its postural attitude. Under the conditions of these observations the dogs would get drowsy, as evidenced by a relaxed body entirely supported by the sling with the head slumping down and the eyes closed, and would go to sleep for various intervals of time.

After some experience it became fairly easy to judge as to when the dog was dozing or asleep and when it was awake. When the observer entered the room of the sleeping dog for any purpose, the animal could often be heard snoring and would wake with a start if disturbed. Records were kept of the behavior of the dog while in the stand and the time when it went to sleep and when it awoke and what the apparent cause of its awakening was. Some dogs would not sleep longer than a minute or two at a time even after three months of daily trials, and such dogs were not used. The dogs that readily went to sleep in the stand were stimulated by the sound emitted from the loud-speaker at various intervals of time after going to sleep, and the intensity of stimulus necessary to awaken the dog was plotted against the length of time the dog had been asleep.

In the work on human beings the subject slept in a bed so arranged that a continuous kymographic record of his motility, as represented by movements of the bedspring, could be obtained each night (See Kleitman, Cooperman and Mullin (4), 1933). The observer was in a non-adjacent room where a light would shine every time the subject moved during the night. When making a determination the experi-

menter actuated the loud-speaker which was located in the subject's room a few feet from the head of his bed. This auditory stimulation was recorded by a signal magnet on the kymograph tracing of the sleeper's motility. If the subject was awakened by the sound of the loud-speaker, he pressed a signal key which sounded a buzzer in the experimenter's room and at the same time made a signal magnet record in the kymograph set-up. It was thus possible for the experimenter to stimulate the sleeper at any time during the night, either with or without reference to the latter's movements, and to grade the intensity of current going into the loud-speaker. When stimulating the sleeper the following routine procedure was employed. The experimenter turned the rheostat dial to 10 and produced that sound for ten seconds. If the subject did not respond, the rheostat was rapidly turned back to 0 for ten seconds and then turned up to 20 and held for another ten seconds, and so on until the sleeper was awakened enough to press the signal key, or until the maximum obtainable loudness was reached.

RESULTS

On the basis of over one hundred and fifty trials on five dogs the irritability to auditory stimuli was plotted against time after the onset of sleep (Fig. 1). For each of the dogs

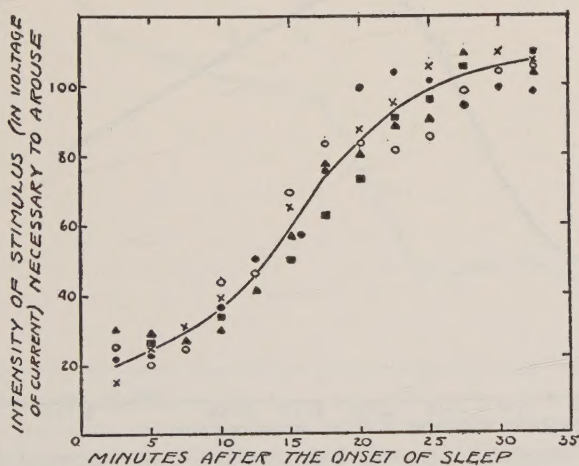


FIG. 1. Irritability changes in dogs following the onset of sleep. The average of the determinations for each of five dogs is indicated by an appropriate mark on the graph at the various time intervals indicated. The curve represents the average of all the dogs together, and records the rise in the threshold of response to sound. This curve is constructed from a total of one hundred and sixty-three determinations.

the result was a curve somewhat S-shaped in character and reaching its highest level in from thirty to forty minutes. The change from the concavity to the convexity in the curve occurred about fifteen minutes after the onset of sleep. Sufficient experimental observations were not obtained to

carry the curve beyond its highest level, but some observations made indicate a gradual return toward the waking threshold during the half-hour following the point of greatest depth of sleep. A few tests were also made on the irritability changes in human beings on first going to sleep. The experimental procedure involved direct observation of the subject by the observer, who stimulated the sleeper at various intervals, after the onset of sleep, in the usual manner with a loud-speaker. The results show a curve of decreasing irritability for the human subjects similar to that seen in the case of the dogs.

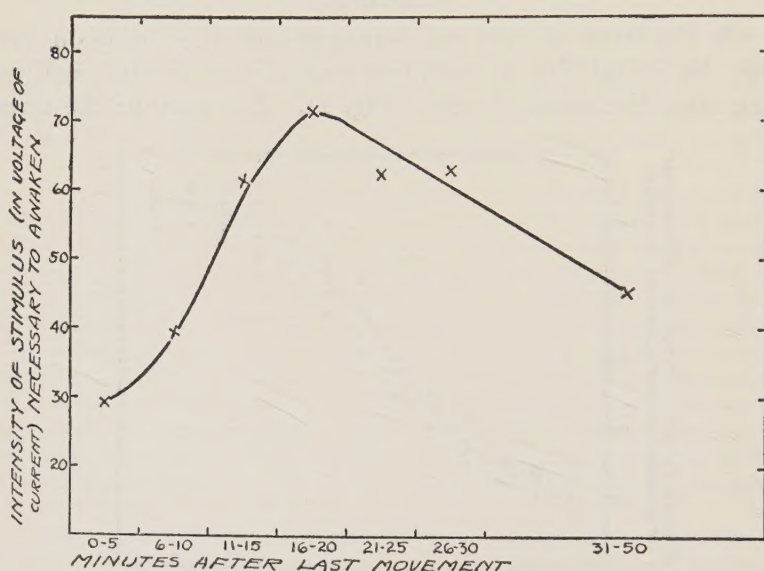


FIG. 2. Irritability changes in human subjects during nocturnal sleep. This curve shows the relationship of the irritability, as measured by auditory stimulation, to the length of time since the last movement of the sleeper. The plotted points represent the average threshold of response of six male subjects as determined by a total of three hundred and twenty-five observations.

The relationship of the average intensity of auditory stimulus necessary to awaken the human subject during the night's sleep to the length of the period of immobility immediately preceding the stimulus was worked out for six male subjects by some three hundred tests. This can be represented by a curve (Fig. 2) which is slightly S-shaped in its

ascent. The change from the concavity to the convexity in this curve occurs in approximately ten minutes, and the height of the curve is reached between sixteen and twenty minutes of immobility. Thereafter the curve of the threshold of response shows a downward direction, indicating shallower sleep. With a few exceptions, the longer the interval of quiescence between pairs of successive movements the higher the intensity of stimulus necessary to awaken, and the more prolonged is the decrease in irritability, no matter what time of night this occurred.

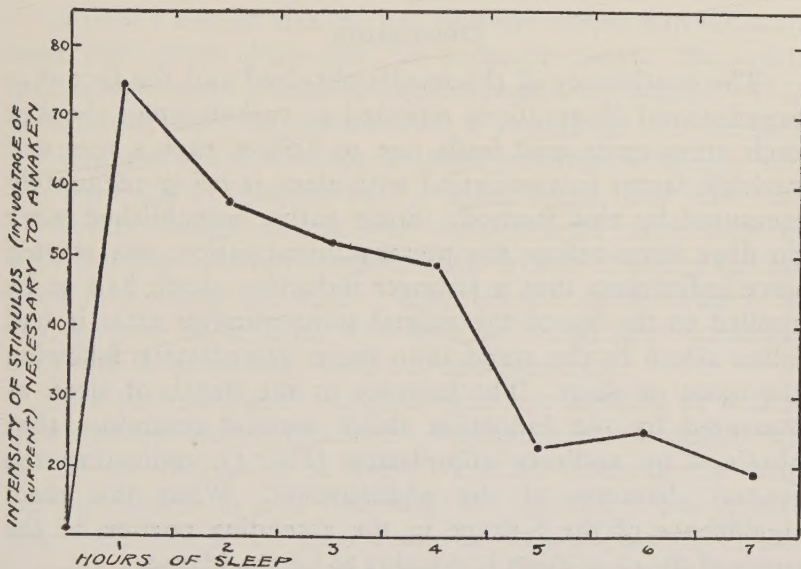


FIG. 3. Irritability changes in human subjects during a night's sleep. This curve is constructed from the same experimental data used for Fig. 2, and each point represents the average change in irritability for successive hours.

If the data that were used for the construction of the curve for the intensity of sound necessary to awaken the sleeper in relation to the time following a movement are now plotted with respect to the hour of the night during which the subject was stimulated, averages are obtained from which a composite all-night curve of the depth of sleep can be constructed (Fig. 3). This curve is none other than the classical depth of sleep curve based on the averages of the

results obtained by random sampling throughout the night on different occasions.

The amount of movement during the night and also the average intensity of stimulus necessary to awaken varied considerably in the different individuals studied. Each of these factors seemed to be characteristic for a given sleeper, but the differences were not always in the same direction. Thus, the most quiet sleeper was also the one most easily aroused, on the average. The same types of motility curve and irritability curves were obtained on all subjects, however.

DISCUSSION

The consistency of the results obtained and the fact that experimental observations repeated at various times checked each other quite well leads one to believe that a real and variable factor in association with sleep is being adequately measured by this method. Some earlier unpublished work on dogs done before the present investigation was started gave indications that a stronger induction shock had to be applied to the leg of the animal some minutes after it had fallen asleep in the stand than more immediately following the onset of sleep. The increase in the depth of sleep as measured by the induction shock method resembles that obtained by auditory stimulation (Fig. 1), indicating the general character of the phenomenon. What the exact significance of the S-shape in the ascending portion of the curve of depth of sleep is remains to be elucidated.

The ascending portion of the curves for dog and for man are similar. The fact that the maximum intensity of sleep in the dog is reached later may be due to a species difference, but may also be due to selective sampling, in that those for the dogs were determined at the beginning of a sleep period whereas the figures for the human subjects were obtained at various hours of the night. The latter are therefore composite figures representing the average of curves of longer and shorter duration.

Following any major type of movement there is a gradual increase and then decrease in the threshold of response to

auditory stimuli. Thus, for human subjects a series of changing irritability curves during successive periods of immobility throughout the sleeping period is more characteristic than the previously elaborated single curve for intensity of sleep. The early studies which yielded the classical curves of the depth of sleep are fully discussed and criticized in considerable detail by Johnson and Swan (3), 1930, who point out the inadequacy of the experimental data and the uncritical nature of some of the conclusions drawn therefrom. Several of these early workers found that it was often harder to awaken a sleeper after he had recently stirred and relapsed back into quiet sleep than at ordinary times. But such results were often discarded for one reason or another. It is of interest that the addition of a record of the sleeper's motility and the correlation between irritability changes and the duration of the periods of quiet sleep show that the irritability changes during sleep are associated rather directly with motility and quiescence, both factors showing similar variations during the night. Each person seems to have his own pattern of motility and level of irritability variations which he tends to follow more or less regularly.

In a normal night's sleep the greatest motility as well as the most frequent spontaneous awakenings of the sleeper fall in the last few hours of sleep. Toward morning the sleep becomes shallower and shallower, as reflected in the greater ease with which the person can be wakened at this time. Occasionally, however, a period of quiescence lasting forty-five minutes or longer will occur toward the end of the night's sleep, and in such cases the depth of sleep curve is similar to those found with the same duration of immobility in the earlier part of the night. This undoubtedly accounts for the secondary peaks found in some of the curves of the depth of sleep reported by earlier workers. Some of the earlier observations on the effects of alcohol and caffeine on the intensity of sleep, as measured by Monninghof and Piesbergen (8), 1883, and also by others since, can probably also be accounted for on the basis of the motility changes caused by these drugs. Mullin, Kleitman and Cooperman (9), 1933,

reported that the relative frequency of motility and spontaneous awakenings during the night after taking these drugs shows that alcohol decreases, and that four and six grain doses of caffeine increase the activity of the sleeper.

A person may wake several times during the night and press a signal key, and yet not recall having done so the next morning. A movement is nearly always associated with such spontaneous awakenings of the sleeper, which occur much more frequently in the last part of the night, but usually the person does not remember on the following morning exactly how many times he signalled. Toward the end of the night's sleep period increasing internal and external stimuli probably combine to make the periods of quiet sleep progressively shorter in duration until finally the sleeper wakes for the day, his irritability level having returned to the waking state.

SUMMARY

1. A method for studying irritability to sound at the onset of and during sleep is described.

2. When a dog falls asleep, the threshold for auditory stimuli rises in a characteristic way and shows an S-shaped curve which reaches its maximum about half an hour after the onset of sleep.

3. A similar curve of irritability changes in the human sleeper is obtained when one plots the intensity of auditory stimulus necessary to awaken against the time after the last movement.

4. Changes in irritability during sleep in the human subject are directly related to the time that has elapsed since the last movement, rather than to the time of night.

5. Each person seems to have a characteristic motility pattern and irritability changes during sleep.

6. The classical curve of 'depth of sleep' does not adequately express the facts relative to changes in irritability during sleep; instead of one continuous curve of intensity of sleep there are many contiguous curves between successive movements, these curves getting briefer and shallower as the night progresses.

(Manuscript received November 27, 1936)

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